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DUAL-TASK TIMESHARING USING A PROJECTED ATTITUDE DISPLAY
(MALCOLM HORIZON)

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NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
PENSACOLA FLORIDA

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Naval Medical Research and Development Command
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SUMMARY PAGE

THE PROBLEM

In order to optimize timesharing and facilitate performance in the high workload environment of the modern cockpit, a Peripheral Vision Horizon Device (PVHD) has been developed which can present aircraft attitude data to the visual periphery; an area reported to be highly sensitive to the perception of information regarding orientation in space. A great deal of subjective evidence gathered from simulator and operational test flights has lent support to the efficacy of this device in improving performance. However, this capability has yet to be verified by controlled laboratory testing. Two horizon sizes were evaluated; one with dimensions similar to that found in an aircraft instrument panel and the other extending out to the visual periphery. The objective of this study was to determine whether dual-task performance could be improved by using the large projected horizon vs. a more conventional short horizon.

FINDINGS

The findings indicated that the PVHD allowed subjects to perform the foveated mental arithmetic task while simultaneously controlling the orientation of the horizon. PVHD root mean square (RMS) error, and mental arithmetic speed/accuracy data were found to be superior when subjects used the extended vs. the short horizon for tracking. These findings suggest that the PVHD permitted individuals to process the two sets of visual information in parallel, thereby improving performance on both.

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INTRODUCTION

The modern aircraft cockpit is a complex, multiple task environment in which pilots must efficiently timeshare their attention among many sources of information. To optimize timesharing and facilitate performance in this high workload environment, a number of alternative avionics systems have been developed. Typically, the design of these systems allow for the presentation of as much information as possible to the pilots central (focal, foveal) field of vision. This is accomplished by 'clustering' the instruments into a small central area on the cockpit panel (8,9,10) or by projecting flight status data onto the cockpit screen as with head-up displays. However, in order to process flight status information, a pilot must focus each instrument or cluster of information serially onto the fovea; a less than efficient process when high workload flight conditions require the pilot to direct attention outside the cockpit for extended periods of time (e.g., aircraft carrier landings, search and rescue operations, air-to-air combat, etc.).

Based on evidence that visual information is encoded and processed by a two-part (central and peripheral) visual system (11,14,16,24) other instruments have been designed to exploit the processing capabilities of the combined central and peripheral (ambient) visual modes. One of these, the Peripheral Visual Horizon Device (PVHD) presents information concerning orientation (attitude) as a thin, horizontal beam of laser light projected across the entire cockpit panel (17,18). Attitude status is thereby made available to not only central vision but can simultaneously be processed using the visual periphery, an area reported to be highly sensitive to the perception of orientation (1,13,15,16). This allows the pilot to use his central field of vision for other tasks while still maintaining orientation through peripheral visual inputs. It is suggested that pilots using the PVHD in this way may be processing two sets of information simultaneously along separate cognitive channels; one monitoring information from the visual periphery and the other from the central visual field.

Subjective data from simulator (3,25) and operational flight tests (2,5,12,21) support the contention that the PVHD does improve performance by reducing workload. However, the cognitive dynamics of this effect have not been studied by controlled laboratory tests. The purpose of this study was to objectively examine workload-related effects of using a PVHD during the simultaneous performance of a non-cognitive tracking (orienting) task and a highly cognitive (arithmetic) task in a controlled laboratory setting.

METHODS

SUBJECTS

Subjects were 16 Naval officers randomly selected from a volunteer pool. All were right-handed and between the ages of 22-30. Subjects had little or no previously accumulated flight hours as a pilot and all were certified in flight-qualified physical health.

APPARATUS

a. Tracking task: Figure 1 illustrates the apparatus used for creating the PVHD. A red neon laser beam was projected via a set of two galvanometer-driven mirrors onto a rear view screen. One rotated the light while the other (vibrating at 40 Hz) spread the beam into an elongated horizon (approximately 30 inches) subtending 56.4° . The smaller, 4-inch horizon was produced by symmetrically blocking the ends of the larger horizon using a wooden 'baffle'. This resulted in a horizon which subtended 8.2° . Oscillating deflections of the beam from the horizontal were produced by input of Gaussian noise at .15 Hz. Each subject tracked the beam to the horizon using an armrest-mounted control stick (Fig. 2). A 2:1 stick-to-horizon deflection ratio provided rapid, accurate responses with horizon movement limited to a maximum $\pm 30^\circ$ deflection from horizontal.

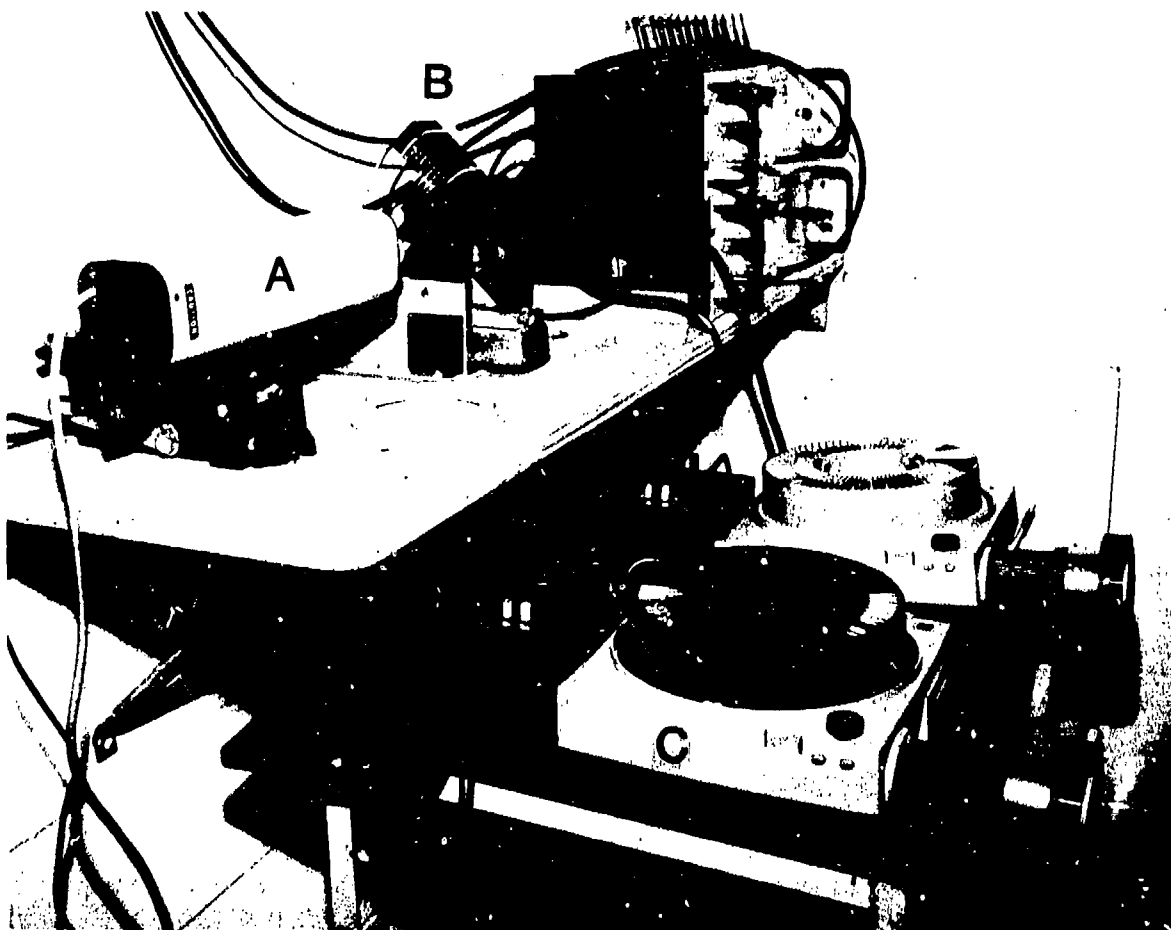


Figure 1

Visual stimulus projection apparatus: A Neon laser (A) projects a thin beam onto a pair of galvanometer-driven mirrors (B) which produce the horizontal spread and rotate the light. The central tasks are projected as slides (C) onto a rear-projection screen.



Figure 2
Subject Performing Tracking and Arithmetic Tasks

b. Mental Arithmetic: A set of slides was projected one at a time onto the rear view screen approximately 24.9° below the horizon centerpoint. Each slide displayed a seven digit number which subtended approximately 6° of visual angle. A verbal response to this task activated a voice actuated relay which, in turn, activated the slide changer.

Procedure

Subjects were divided into four equal groups in order to partially counterbalance the sessions for order of horizon presentation (Table I). All instructions were administered verbally.

An initial 2-minute practice period was provided in order to allow each subject to become acquainted with the dynamic response of the control stick and the nature of the arithmetic task. During this practice period, each task was presented alone. The projected line was tracked to the horizontal and maintained. The arithmetic task involved mentally adding the first six digits of the string, subtracting the seventh from that sum, reporting the result verbally and the response would trigger the voice actuated relay resulting in presentation of the next slide.

TABLE I

Presentation Order of Small and Large Horizons for 4 Subject Groups

| ORDER OF PRESENTATION | | | | |
|-----------------------|-------|-------|-------|-------|
| GROUP # | 1 | 2 | 3 | 4 |
| 1 | LARGE | SMALL | LARGE | SMALL |
| 2 | SMALL | LARGE | SMALL | LARGE |
| 3 | LARGE | SMALL | SMALL | LARGE |
| 4 | SMALL | LARGE | LARGE | SMALL |

The subsequent experimental session was divided into four test periods, each 16 minutes long. Subjects performed both tasks simultaneously for one minute, tracking either the large horizon (LH) or short horizon (SH). They were instructed to perform both tasks as quickly and as accurately as possible. Tracking RMS error and arithmetic task response latency and accuracy were recorded on magnetic tape. This was followed by a one-minute rest period during which the subject was given verbal feedback concerning how well he performed on the tracking task. This assessment was based on an error score derived from RMS voltages summing over time with increasing tracking error. This score ranged from 1-100 volts, with the lower number representing less accumulated error, therefore, a better score. After reporting this score during the rest period, each subject was told if it was better or worse than the previous error value. At the end of the session, each subject was asked to describe the strategy used to perform both tasks. All responses were recorded. The total duration of each experimental session was approximately 90 minutes.

RESULTS

The root mean square (RMS) error values for each horizon size were averaged across the four experimental groups. A correlated T-test for repeated measures revealed a significant difference between tracking error as a function of horizon size ($t=5.67$, $df=15$, $p<.01$). The mean RMS error for the LH was lower ($\bar{x}=0.53$, $SD=.08$) than that of the SH ($\bar{x}=0.74$, $SD=.09$).

Faulty analog storage precluded using Subject 1's correct response data in the present analysis. A significant difference was observed in a horizon-based comparison of correct answers on the arithmetic task. Subjects averaged more correct answers using the LH than the SH ($t=3.53$, $df=14$, $p<.05$). A repeated measures (treatment-by-subjects) analysis of variance was

also performed on the accuracy data. The results are summarized in Table II. Treatment effects were found to be significant ($F=6.30$ (1,14), $p < .05$).

TABLE II
Analysis of Variance Source Table for Correct Response Data

| Source | SS | Df | MS | F | P |
|------------|-------|-----|------|------|------|
| Total | 74.38 | 29 | | | |
| Subjects | 72.31 | 14* | | | |
| Treatments | 0.63 | 1 | 0.63 | 6.30 | <.05 |
| Error | 1.44 | 14 | 0.10 | | |

*Correct response data for subject #1 was not used in analysis

The latency to responding was measured and compared across groups. The results indicate that there was significant difference between the speed of response as a function of horizon size ($t=3.09$, $df=15$, $p < .01$). An analysis of variance also showed significant treatment effects ($F=6.05$ (1,15), $p < .05$). The source table for this ANOVA can be seen in Table III.

TABLE III
Analysis of Variance Source Table for Response Latency Data

| Source | SS | Df | MS | F | P |
|------------|-------|----|------|------|------|
| Total | 74.45 | 31 | | | |
| Subjects | 70.45 | 15 | | | |
| Treatments | 1.15 | 1 | 1.15 | 6.05 | <.05 |
| Error | 2.85 | 15 | 0.19 | | |

DISCUSSION

The results of this study indicate that the PVHD allows an individual to perform a foveated cognitive task while simultaneously controlling the position of a moving horizon projected across the entire field of view. Subjects reported that they could more easily track the LH and did not have to fixate on the horizon in order to perform both tasks. It was necessary, however, to continually shift gaze, fixating on each task while tracking the SH. This confirms earlier findings of Navon and Gopher (20) which indicated that competition for foveal resolution (resulting in a performance decrement) occurred when the location in space of two stimuli necessitated the use of common channels of information input (e.g., eyes, ears, etc.). However, LH tracking data in this study suggests that individuals tracking the PVHD may have relied on inputs from the composite field of central and peripheral vision (19), and their ability to process both inputs was facilitated because the moving horizon was presented primarily to the orientation-sensitive visual periphery.

Figure 3 illustrates this difference in tracking ability (RMS error) based on horizon size. Performance was clearly superior when the LH was paired with the cognitive task. The RMS error of the SH consistently remained significantly higher than that of the LH dual-task responding. The PVHD

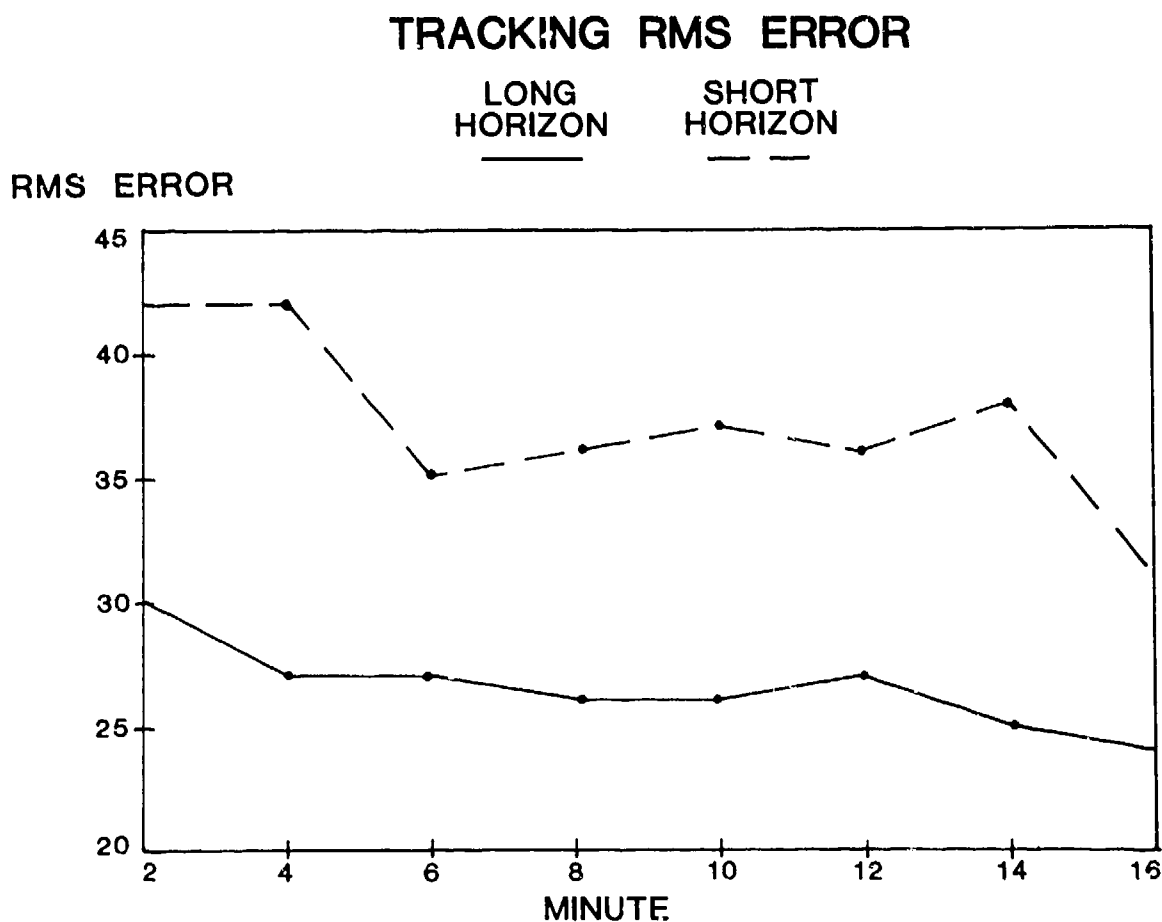


Figure 3

Tracking Root Mean Square (RMS) Error as a Function of Horizon Size

was made available to peripheral vision while subjects foveated the arithmetic task. The larger horizon provided them with the orientation information necessary for horizon stability. When using the smaller horizon, subjects were not able to easily scan between both tasks and were therefore unable to track the SH as efficiently. The requirement to place each task within central vision necessitated a wide scan thereby increasing RMS error even from the outset of each trial. This implies that with the LH individuals need not constantly scan back-and-forth in order to efficiently "attend" to both stimuli simultaneously.

The latency to responding (defined as the length of time from stimulus onset to the first response utterance) as a function of horizon size is illustrated in Figure 4. There is an overall significant difference between SH and LH latencies, with LH responses occurring more rapidly. This suggests that the PVHD facilitates the rate of cognitive task processing by enabling the individual to foveate the arithmetic task without requiring him to sub-

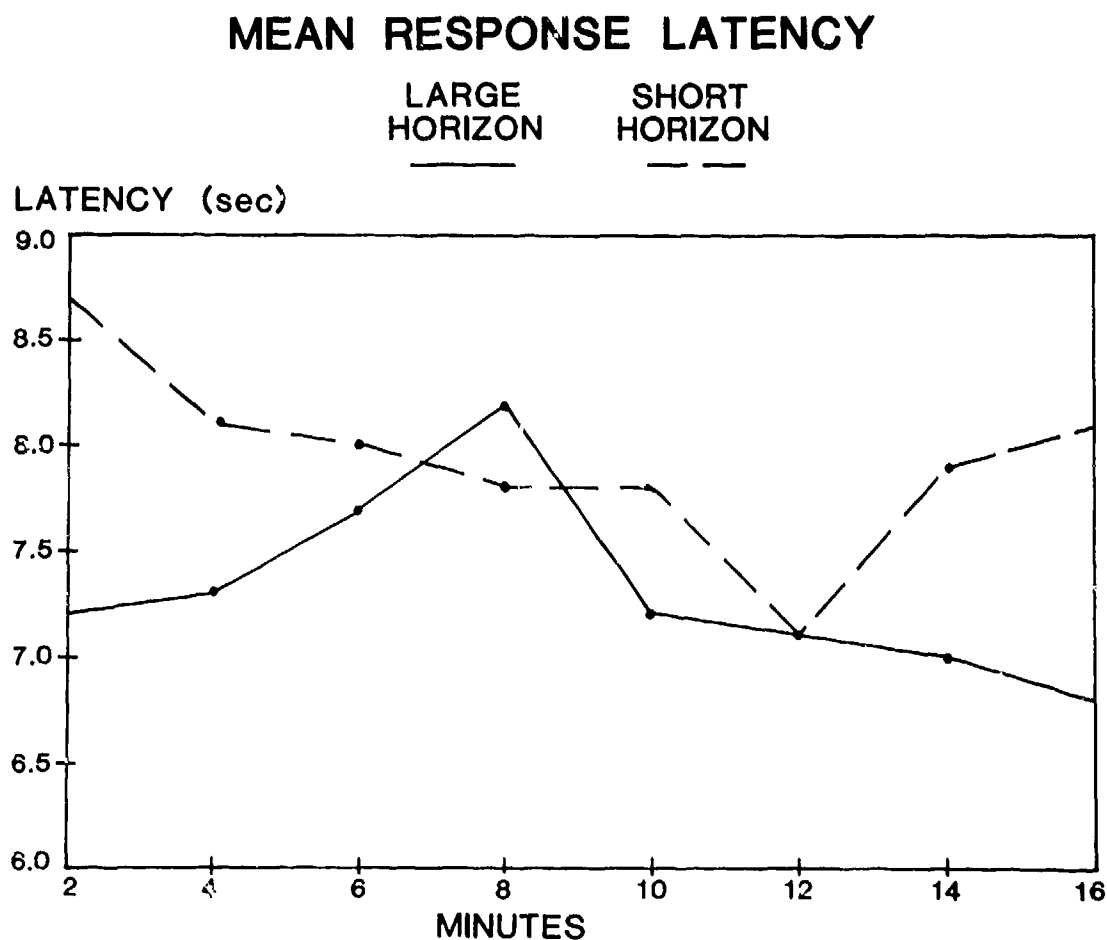


Figure 4

Average Arithmetic Task Response Latency as a Function of Horizon Size

sequently shift his gaze to a distant data source. Processing can therefore occur more rapidly. Recent evidence suggests that when a cognitive task is performed concurrently with instrument monitoring, effective scanning is disrupted (6,26). The result is impaired processing which is manifested as response delays. The data from this study demonstrates the ability of the PVHD to significantly diminish this effect.

Response accuracy was likewise enhanced by the PVHD. In both cases (LH and SH), the number of correct responses slightly increased over time (Fig. 5). However, arithmetic responses paired with the LH were more accurate than those during the pairing with the SH. It is noted that at minutes 2, 3, and 12, LH values dropped below those of the SH. While an immediate explanation for this effect is unclear, it is possible that pronounced individual response differences were incorporated into the grouped subject analysis. Indeed, of the variables measured, response accuracy varied most within subjects possibly due to the difficulty or novelty of the test, or fatigue and boredom. It is apparent from the data that subjects were not performing a speed/accuracy tradeoff; that is, the sacrifice of speed for accuracy (and vice versa). In the event of a tradeoff, a higher degree of accuracy would be significantly correlated with slower response times. In the present case, responses were similar to those reported by Harris et al. (7) who found that response speed covaried with response accuracy. This effect might be seen if attention were divided between the cognitive and tracking tasks. However, the result of that would be significant changes of RMS error over time, a variance not observed in the error values for either horizon.

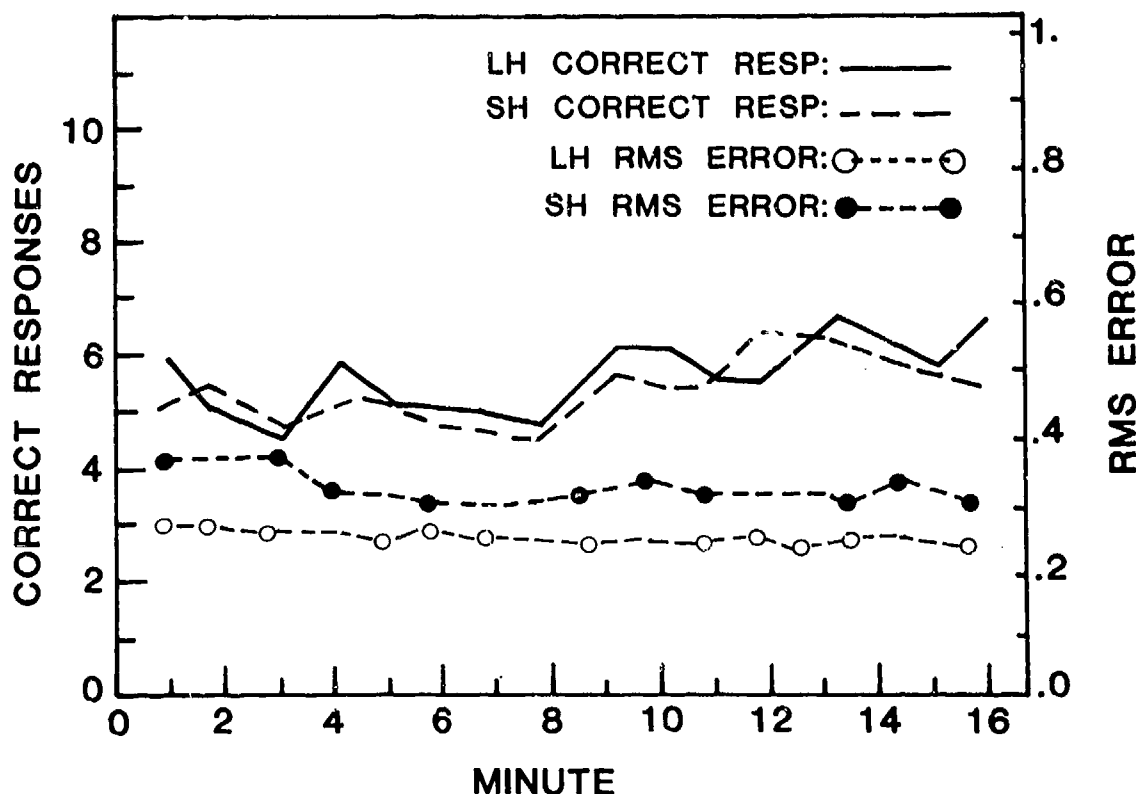
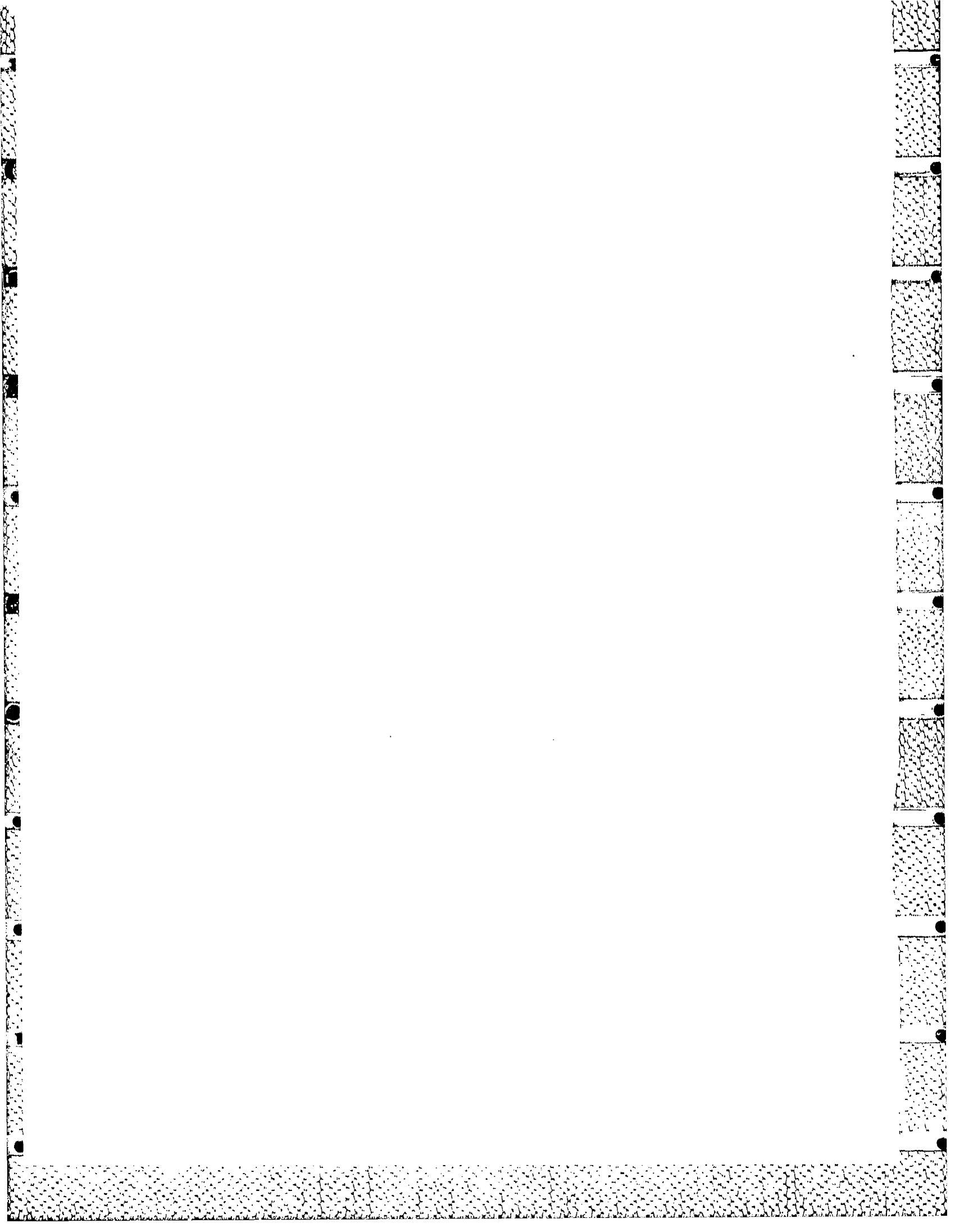


Figure 5
Average Number of Correct Arithmetic Task Responses and RMS Error as a Function of Horizon Size

An alternative explanation for this speed/accuracy covariance may lie in the ability to perform PVHD tracking without the use of resources (22). The lack of significant RMS error changes during simultaneous arithmetic task performance indicates that resources required to perform the cognitive task were accessed without interference from the other task, an effect commonly found in dual-task pairings (4,27). This implies that resources necessary to perform both tasks originate from different pools (23) or that PVHD tracking is performed independent of resource allocation.

In summary, it was found that dual-task performance could be improved by using a large projected horizon vs. a shorter, more conventional horizon. The findings suggest that the PVHD permitted individuals to process the two sets of visual information in parallel, thereby improving performance on both.



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